Energize Missouri:
Algae-Based Renewable Energy Study

Task G
Recommend Collaboration

Final Report

For
Missouri Technology Corporation

MRIGlobal Project No. 110754.1-G

August 17, 2011

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For
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Jefferson City, Missouri 65102

Attn: Jason Hall

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Preface

This report was prepared for the Missouri Technology Corporation under a subgrant award to MRIGlobal and entitled "Energize Missouri: Algae-Based Renewable Energy Study" signed by Mr. Jason Hall and dated February 28, 2011. Work was initiated in accordance with a work plan submitted and approved on March 11, 2011. The project team includes members from MRIGlobal, Washington University in Saint Louis, and the University of Missouri, Columbia.

The objective of the grant is to produce a study to help define the development and commercialization of algae as a fuel source that would be a valuable adjunct to the state energy plan. The study would emphasize the potential benefits to the state economy that a commercial algae industry could bring, opportunities for Missouri to become a leader in such an industry, and the policy steps and collaborations that the state could initiate to strengthen Missouri's leadership in this area. The study is divided into seven (7) tasks plus a final report. This report is the results of Task G which was to identify and recommend opportunities for Missouri to collaborate with other states and countries that have algae-based research, commercialization and production expertise.

This Task G study was authored by Stanley Bull of MRIGlobal as Principal Investigator. The author wishes to acknowledge contributions by Bill Babiuch, Tom Grant, Tom Johnson, and Jay Turner.

MRIGLOBAL

Stanley Bull, Ph.D.
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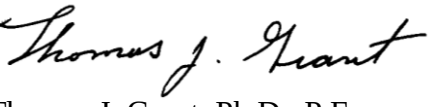
Approved:



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Section 1.
Introduction

1.1 Study Motivation and Scope

Algal production of biofuels requires a unique blend of expertise from various technical fields including biology, chemistry, and engineering. Algal biofuel production is technically feasible, but faces economic and logistical challenges. Outdoor (open pond) production requires adequate land, abundant supplies of water and nutrients, and an acceptable climate. These resource demands tilt the playing field to favor certain geographic locations, but comparative siting assessments are few and limited in scope. Downstream processing of the algae to make biofuels is also equipment and energy intensive. A vast number of producers, processors, equipment suppliers, and other service providers are needed if algal-based biofuels are to replace a significant portion of petroleum-based fuels. Given its location and resources, the State of Missouri may have locations within its borders suitable for algae production and processing. Further, Missouri's strong industrial and agricultural base could be great assets for the growth of equipment suppliers and services to support this nascent industry. Given the importance of transportation fuels to the nation's economy, the economic and employment payoffs could be substantial.

The purpose of this study is to evaluate the potential for Missouri to serve as a center for various aspects of the algal biofuel production enterprise. The tasks are as follows:

A. Assess the potential for algal biofuels to help meet the energy needs of Missouri and the United States.

B. Identify and document Missouri's algal biofuels research, resource, and industrial assets.

C. Compare Missouri's algal biofuels research, resource, and industrial assets to those of other states and countries to examine Missouri's competitive advantages, and to identify areas where greater efforts are needed.

D. Identify opportunities for Missouri to be a leader in supplying products and services to implement commercially viable production systems for algal biofuels.

E. Identify technical, regulatory, and fiscal challenges that prevent or hinder broad implementation of algal biofuels production systems.

F. Recommend strategic policy initiatives that Missouri could pursue to advance the large-scale implementation of algal biofuels systems.

G. Identify and recommend opportunities for Missouri to collaborate with other states and countries that have algal research, commercialization, and production expertise.

This report for Task G identifies and recommends opportunities for the State of Missouri to collaborate with other states and countries that have algae research, commercialization, and production expertise.

1.2 The Framework for Collaboration

Tasks A through C have analyzed the potential for algal biofuels to help meet the energy needs of Missouri and the United States, identified Missouri's algal biofuels research, resource, and industrial assets, and compared Missouri's competitive advantages relative to other states and countries. The three principal broad areas identified in these Tasks as opportunities for Missouri to be a leader in the algae arena are as follows:

1. Research and Development
2. Equipment Manufacturing and Engineering
3. Algal Biofuels Production

The Sections below will describe both existing collaborations and recommendations for future collaborations based on an understanding of the current assets and the opportunities those portend.

Section 2.
Recommendations for Collaborations

2.1 Research and Development

Research and development in biotechnology as applied to agriculture is a major strength in Missouri with heavy concentrations in the St. Louis and the Kansas City areas. The development of methods for the production of algae is seen to be heavily dependent on agricultural science and operational approaches. Missouri enterprises are providing national and international leadership in research and development today.

The Donald Danforth Plant Science Center (DDPSC), Monsanto, and Washington University in St. Louis (WUSTL) lead a collaboration of world-class plant research programs that are leading the science forward and resulting in spin off companies to take the technologies to commercialization. DDPSC is the Consortium Team Lead for the National Alliance for Advanced Biofuels and Byproducts (NAABB), which is a U.S. Department of Energy (DOE) funded Algal Biofuels Research Consortium. Two DOE Energy Research Frontier Centers (EFRC) are based in St. Louis—the Center for Advanced Biofuel Systems (led by DDPSC) and the Photosynthetic Antenna Research Center (led by WUSTL). MRIGlobal, based in Kansas City, established a Center for Integrated Algal Research to bring together cross-disciplinary teams to identify and optimize algal species performance in facilities in both Missouri and Florida. Other research specific to algal biofuels production is currently underway in the state at the University-Columbia and the Missouri University of Science and Technology in Rolla.

The NAABB with DDPSC as the Consortium Team Lead has a goal of breaking down barriers to commercializing algae-based biofuels by producing new technologies that can be implemented by the algal biofuels industry. In order to achieve their goal, the program incorporates objectives in algal biology, cultivation, fuel conversion, harvesting, sustainability, and agricultural co-products. The NAABB is an excellent example of extensive collaboration to access complementary capabilities from states across the U.S. This collaboration consists of more than 30 independent partner entities including DOE National Laboratories in New Mexico and Washington; Universities in Arizona, California, Colorado, Iowa, Michigan, New York, North Carolina, Pennsylvania, Texas, Washington; and industries in numerous states including Hawaii. The reach and extent of the NAABB collaborations is impressive and can serve as a model for future Missouri research and development collaborations.

The Center for Advanced Biofuel Systems at DDPSC seeks to increase the efficiency of select plant- and algal-based oil and specialty fuel production systems using metabolic engineering approaches grounded in modern systems biology. The distinguishing feature of this Center is that it integrates all aspects of metabolism, from light capture in photosynthesis through end product production. DDPSC leads a team of university collaborators from the states of Michigan, Nebraska, and Washington.

The Photosynthetic Antenna Research Center is focused on a basic science approach to understanding the process of light collection in natural, artificial, and hybrid antenna complexes. The key outcome is to understand how these processes can be used to drive efficient sources of energy for human benefit. WUSTL leads a team of three DOE National Laboratories in New Mexico and Tennessee; U.S. Universities in California, North Carolina, and Pennsylvania; and U.K. Universities in Scotland and England.

MRIGlobal has had long standing involvement in algal research and development dating back to the 1980s as the Management and Operating Contractor for the DOE Aquatic Species Program (ASP) at the Solar Energy Research Institute (SERI), later the National Renewable Energy Laboratory (NREL). Collaborations were a key element of the ASP until funding was terminated by DOE in 1996. MRIGlobal currently has both laboratory and outdoor algae growth facilities in Missouri and Florida. Through the Florida operations several collaborations with both universities and industries are currently active. MRIGlobal also maintains a collaborative relationship with Israeli algae entities.

2.1.1 Recommendations

Broad R&D collaborations with Missouri taking the lead are already very robust. The State of Missouri should:

- Encourage and support these collaborations through strong support for higher education within the state.
- Provide cost share funding to enable collaboration with federal agencies through research and development contracts.
- Use the power of the state to convene large state industries (e.g., Monsanto) to stimulate collaboration with research and development organizations both within and outside the state to transition the R&D to industry and for economic development.
- Appoint a lead within MTC to monitor and keep state entities informed on the status of the development of algal technology.

2.2 Equipment Manufacturing and Engineering

As presented in Tasks A through C, Missouri's industrial machine manufacturing enterprise covers a wide variety of manufacturers who export their equipment outside the state. The industry includes over 580 different establishments with average wages of more than $42,000 per year. These industries produce a variety of machinery including mining equipment, tractors and vehicles, lawn mowers, waste disposers, industrial molds, scales, freezers, and furnaces. Existing manufacturing establishments are concentrated in eight areas, including St. Louis, St. Joseph, Columbia, Ava, Sedalia north to Slater, Camdenton, and Hannibal. In addition, the Farm Equipment Manufacturers Association is located in St. Louis.

As the algae industry develops and reaches commercial viability in the U.S. and other countries, opportunities for new types of equipment and the engineering design, build, and operation of the facilities will emerge. The light manufacturing and construction companies will be well suited for quickly developing prototypes and systems and the required design generations that will follow. The areas of algae harvest, dewatering, drying, and oil extraction will be the source for the need of light industrial equipment capabilities. Today, there are very few equipment manufacturing companies working to support the fledgling algae industry.

Algae production will require the efficient movement of large quantities of water. Engineering and construction firms working in the areas of wastewater treatment facilities will be well positioned to support a growing algae industry. Two world class engineering, design, and construction firms are headquartered in Kansas City, Burns & McDonald and Black & Veatch have extensive experience in large water projects and related areas.

2.2.1 Recommendations

Missouri has excellent equipment manufacturing and engineering capabilities available to be very competitive in support of a growing algae production and processing industry. The State of Missouri should:

- Collaborate with states and countries with algae to biofuel operations to foster innovation in manufacturing and to be the first to market new equipment required by an algae industry.
- Facilitate the transition of manufacturing lines to enable capturing a large market share.
- Consider developing a high tech focused manufacturing cluster with nearby states centered in an area of current manufacturing strength.
- Develop collaborations internationally as a means to open up off shore markets for the products manufactured.
- Bring an awareness of the future opportunity in the algae industry to the engineering firms in the state.

2.3 Algal Biofuels Production

Missouri is not currently typically thought of as the most promising state for location of an algal production facility because states further south have a warmer climate. However, Missouri is home to a measureable aquaculture industry in the state with 47 members registered with the Missouri Aquaculture Association. Most of these businesses are small fish farms to supply local stocking and recreational fishing supplies and not businesses that utilize on-site algae production for fish meal for high production fish farms. In the U.S., the most common algal production facility is for the production of algae biomass for food on-site fish farms or for high value pharmaceutical and nutraceutical products. These operations are located in Hawaii and the southern tier of the continental U.S. to facilitate year-round production without risk of disruption

from freezing. Also, many of the existing operations are located in proximity to salt water because of lack of general abundance of fresh water for such uses.

Task D provides a description of the Bootheel region of the state as being a potential opportunity for algal production because of the flat land, abundance of water, and a warm, humid climate. Further, there are associated opportunities to locate near electric utility power plants to make use of the carbon dioxide emissions and waste heat for winter warming of the ponds, and to use waste water from nearby municipalities.

The current estimate of biofuels costs from algal production are at least four times the costs of traditional fuels. The advancement of science and technology will certainly reduce that cost over time; however, that time frame is likely to be in the range of 10 or more years. This time frame can be reduced by the development of co-products of value, such as protein or nutraceuticals that can effectively subsidize the cost of the biofuel. Missouri is an agricultural state; and it therefore, has many farmers who know well how to grow crops and how to minimize the cost of growing them. Missouri could be a leader in helping to transform the paradigm of algal production from an industrial process and move instead to an agricultural operation to be carried out by farmers. To be sure, it is not the traditional farming techniques practiced by farmers, but with the help of the MTC, gaining experience from the aquaculture industry, and some incentives a transition could be made.

Countries outside the U.S. have expressed an interest in collaborations. Among these are South Korea, Israel, Singapore, and Australia, For example, South Korea has established an Advanced Biomass R&D Center and provided $200M over 9 years, and they are openly stating they are seeking collaborations. Israel has had long standing interest in collaborations with the U.S. The Australian government has expressed a desire to partner with other countries to accelerate the development of algae applications. Singapore is an opportunity in that the tax structure there is favorable and startup operations are seeing that location as an advantage.

2.3.1 Recommendations

Missouri will need to rely on innovation and resourcefulness to become a serious player in algal production. The State of Missouri should:

- Conduct a detailed analysis of the Bootheel region for viability of algal production.
- Collaborate with Arkansas and Tennessee to develop a pilot scale algae facility in the Bootheel region.
- Bring the Missouri Farm Bureau and the Florida Aquaculture Association together to develop a Missouri farmer approach to algal production.
- Develop at least one international collaboration (e.g., South Korea) where there is known interest and investment in algal production.

Section 3.
Summary Recommendations

3.1 A Midwest Home for Algae

Task G was to identify and recommend opportunities for Missouri to collaborate with other states and countries that have algae-based research, commercialization, and production expertise. The four key recommendations for collaborations are as follows:

1. Missouri is now a leader in developed collaborations outside of the state in algal research and development; it is important to not lose the momentum that exists and it is recommended that the European Union and South Korea be explored as potential partners as well.
2. Missouri has significant strengths in equipment manufacturing and engineering expertise that can be transitioned to accommodate and be competitive in the algae process business and it appears collaboration would be of benefit if it can result in a supplier role in international markets in the European Union and South Korea.
3. Missouri should consider developing a pilot scale algae facility in the Bootheel region and seek to collaborate with the states of Arkansas and Tennessee in this endeavor.
4. Missouri has the opportunity to collaborate with other states (South Florida is the best opportunity because MRIGlobal has operations in both Missouri and Florida) to achieve cost effective algal production by transitioning conventional farming practices to algal aquaculture operations using know how for minimizing costs of operation.

Perhaps the “Show Me” label for Missouri is just another way to say, “Let’s Collaborate.”